Proceedings of the Integrated Crop Management Conference

Proceedings of the 11th Annual Integrated Crop Management Conference

Dec 2nd, 12:00 AM

Managing Phosphorus: Agronomic and Environmental Concerns

Regis Voss
Iowa State University

MANAGING PHOSPHORUS: AGRONOMIC AND ENVIRONMENTAL CONCERNS

Dr. Regis Voss
Professor Emeritus
Department of Agronomy
Iowa State University

Introduction

Phosphorus (P) is an essential nutrient for terrestrial and aquatic plants. We recognize the beneficial effects of P on the growth and yields of beneficial crops. There is increasing concern and attention being given to phosphorus losses from agricultural soils. Substantial amounts of P entering surface waters (lakes, other surface impoundments and streams) contribute to accelerated eutrophication of lakes and reservoirs. Eutrophication is a process by which a water body becomes rich in dissolved nutrients and, often, seasonably deficient in oxygen. Eutrophication due to excessive algal and other plant growth and their ultimate decomposition, which consumes oxygen, limits the use of surface waters for aesthetics, fisheries, recreation, industry and drinking.

In recent years there has been a change to more intensive agricultural production systems, especially the localization and intensification of animal production systems. With this intensification has come a buildup of soil P levels in site-specific areas to levels rarely encountered in past decades. As a result, there is increased potential for P losses from these site-specific areas and environmental risk to affected surface waters. Many of these high P soil test areas are located near sensitive water bodies. When adsorption sites for P in the soil become saturated, P is potentially more available for runoff and leaching losses. Traditional soil test extractants for P were developed by research to provide indexes of P availability to plants. There currently is no standardized P testing procedure to identify critical soil P levels associated with environmental risks. There is a need to develop field/soil measurements to help identify P problem areas and to target these areas with acceptable management practices to achieve satisfactory economic and environmental solutions.

The Problem

There is a general conclusion that aquatic growth in inland surface waters is P-limited, i.e., as P concentration in surface water increases, aquatic growth increases. According to the National Research Council (1993), overall trends indicate about equal numbers of U. S. rivers with increasing and decreasing P loads. In general, decreases are linked to point source reductions and increases are linked to nonpoint source increases that are associated with increased sediment loads and agricultural land use.

The critical concentration of P associated with accelerated aquatic growth is very low, 0.01 parts per million (ppm), but a range of 0.01 to 0.03 ppm seems to be accepted (National Research Council, 1993). These values are roughly one-tenth of the soil solution concentration critical for plant growth. The U. S. Environmental Protection Agency (US EPA) has not yet developed P water quality criteria for fresh water bodies, but has established 0.001 ppm elemental P as a criterion for marine and estuarine water (Parry, 1998). Daniel et al. (1998) stated, however, that water quality criteria have been established to control eutrophication (US EPA 1986). For example, total P should not exceed 0.05 ppm in streams entering lakes/reservoirs, nor 0.025 ppm within lakes/reservoirs. For the prevention of plant nuisances in streams or other flowing waters not discharging to lakes/impoundments, the concentration of total P should not exceed 0.10 ppm. A dissolved P concentration of 1 ppm is the limit required of sewage treatment output and one advocated by some as a critical flow-weighted-mean-annual concentration for agricultural runoff.

Transport of Phosphorus

Phosphorus can reach surface waters as P dissolved in runoff water, P attached to soil particles contained in soil erosion, and P contained in tile effluent. Not all agricultural land, nor all that contained in a watershed, contributes to any or all of these processes.

Phosphorus potentially available to algal uptake is termed bioavailable phosphorus (BAP), which is comprised of dissolved phosphorus (DP) and particulate forms of phosphorus (PP). Dissolved P is mostly available for algal uptake, but PP, associated with eroded sediment and organic matter, contributes a variable but long-term source of BAP (Sonzogni, 1982; Sharpley and Smith, 1991).

If runoff containing DP and PP from agricultural fields enters a surface stream the DP may be adsorbed (concentration decreases) by stream sediments or PP may be desorbed (DP concentration increases), depending on the P sorption saturation of the stream sediments. Thus the concentration and amount of BAP entering a lake/reservoir may be different from that leaving an agricultural field. Sediments with high P concentrations entering a lake/reservoir can contribute BAP by desorption for a prolonged period of time.

The effect of BAP entering lakes or surface impoundments on eutrophic growth depends greatly on their characteristics. Turbidity, depth of water, flushing rate, stratification, and background P level of lakes/reservoirs affect growth of algae and other aquatic vegetation. In general, P control strategies have greatest benefit on deeper, stratified lakes with a low flushing rate (less than six times per year) and low background levels of P.

Phosphorus Loss from Agricultural Fields

Studies have found higher concentrations of DP in surface water runoff from no-till fields with surface crop residue than in runoff from conventional-till fields (e.g., Romkens et al., 1973). Also, studies have identified higher runoff concentrations from fields covered with frozen crop residue, such as alfalfa, than from tilled fields (e.g., Wendt and Corey, 1980), and from fields with surface-applied, non-incorporated fertilizer and/or manure than from fields with incorporated fertilizer (e.g., Truman et al., 1993).

Rainfall interacts primarily with the 0- to 2-inch layer of surface soil (e.g., Oloya and Logan, 1980; Sharpley and Smith, 1989). As a consequence there is a very good positive relationship between soil test P levels and concentrations of DP in runoff (e.g., Pote et al., 1996), as shown in Figure 1. Losses are exacerbated by stratification of surface applied P in no-till and conservation tillage systems, where soil test P levels are highest in the 0- to 2-inch layer (Triplett and Van Doren, 1969; Robbins and Voss, 1991).

There has been a general increase in soil test P levels in the U. S. since World War II as a result of P applications. A 1989 summary of soil test values showed that in several states more than 50 percent, and in some states 75 percent, of soil test P samples tested high (PPI, 1994). A recent soil test summary from 1997 (PPI/PPIC/FAR, 1998) indicates that many agricultural soils remain in the high and very high categories. For many states, percentages of tests with high P levels are similar to 1989 percentages, but trends show decreasing numbers of tests with high P levels in some important agriculture states in the Midwest, such as Indiana, Illinois, Iowa, Minnesota, and Ohio. In other states, such as Arkansas, Wisconsin, North Carolina and Delaware, soil test P levels continue to increase.

A nutrient budget analysis for the states of Iowa and Wisconsin, indicates that these up or down trends might be explained based on P use and removal. Assuming that all collectable manure in Iowa was applied to cropland, P removal by crops exceeded the inputs in 1996 by 10 percent. In Wisconsin P crop removal is only 84 percent of P inputs (Bundy, 1998). In many cases the problem of elevated soil test P levels are associated with regions where intensive animal production facilities exist and animal manure supplies exceed crop needs on available agricultural land. County-based estimates of the potential for P available in animal manure to meet or exceed crop removal are available to identify local soil test P problem areas (Lander et al., 1998). The potential for P loss from surface runoff and, in some situations, subsurface leaching, increases as soil test levels exceed critical soil test values established for crop needs (Sharpley et al., 1996).

Because commonly used soil test procedures, e.g., the Bray and Kurtz P-1, Mehlich III, and Olsen tests, were developed to provide indexes of P availability to plants, a more rigorous test is desirable to indicate the loss of DP for environmental interpretation. Soils will adsorb or desorb P depending upon the P sorption saturation of the soil, which is defined as:

$$\text{P sorption saturation} = \frac{\text{Extractable soil P}}{\text{P sorption capacity}} \times 100$$

More P is desorbed (or released) from soil and lost through runoff or leaching as P sorption saturation increases (Figure 2). A better relationship was found for DP concentration and P saturation than for DP concentration and soil test P indexes (Sharpley, 1995). The P sorption saturation test provides an integration of soil characteristics, but it is time consuming and costly. This method, like routine soil tests, does not predict total loss of DP, which depends on runoff volume. The P sorption saturation approach does indicate potential for loss of DP. The Dutch have designated a critical P saturation value of 25 percent (Van der Molen et al., 1998).

Phosphorus in Eroded Soil Sediment

Phosphorus associated with eroded soil sediment is termed particulate phosphorus (PP). Eroded sediment tends to have a higher P concentration than its original source, but excessive soil erosion may dilute the concentration in the total eroded sediment. Particulate P can be 75 to 90 percent of the P transported in runoff (Schuman et al., 1973).

Although PP loss may be greater than DP loss, only a portion of PP is bioavailable phosphorus (BAP) because some of the adsorbed P will not desorb and is not available to plants. P extracted by a sodium hydroxide solution is more closely associated with BAP concentration and availability to algae than is soil test P (e.g., Wolf et al., 1985). A simpler procedure using iron oxide-impregnated paper strips to determine the BAP directly related to algae growth was adapted by Sharpley, 1993a,b (see Figure 3). The iron-oxide strips function as a P-sink, adsorbing P released from soil sediment, and simulating P removal by algae.

Although specific analytical procedures provide indexes of P that are related to concentrations of DP, PP, and BAP loss in runoff water and eroded sediment, test results are not reliable indicators of P amounts lost from fields or arriving to surface waters. Test results do indicate a potential for loss, if combined with estimates of runoff or erosion potential.

Phosphorus in Tile Effluent

Because P is considered to be immobile in the soil, there is generally little concern that it will be lost in tile drainage. There are, however, locations with sandy or organic soils where tile effluent has high concentrations of P (Duxbury and Peverly, 1978). In the Netherlands, where sandy and organic soils with high water tables are prevalent, restrictions on P use are imposed. Studies in the United States have in general found very low concentrations of DP in tile drainage, but concentrations frequently exceed the projected critical value of 0.01 ppm P for algae growth (e.g., Baker et al., 1975). In one study, P concentrations in tile effluent increased as rates of manure increased, indicating that excessive manure loading can contribute to DP loss even though economic loss is negligible (Hergert et al., 1981).

Immediate concerns are to manage and monitor P concentrations in tile drainage from areas where soil P concentrations are already very high, soil P sorption capacities are low, and subsurface transport is enhanced by tiles and surface ditches. Phosphorus saturated soils could lead to prolonged loss of DP in tile effluents. In many situations, loss of P in tile effluent will be of little consequence relative to surface runoff and erosion, e.g., in fine-textured soils that are judiciously fertilized in accordance with soil testing recommendations and that have low degrees of P saturation.

Problem Assessment

Because of the diversity in the agricultural landscape, there is a wide range in the potential loss of P from fields within the landscape. Contributing to the diversity are: physical and chemical characteristics of the soils, landscape form, crop and plant vegetation, crop production cultural practices, P level of the soils, and method of P application. Most watersheds contain field sites that are different in one or more characteristics. To assess the potential risk of P movement to surface waters from various landforms subjected to different management practices, a Phosphorus Index was proposed by Lemunyon and Gilbert, 1993. This index considered eight weighted factors: soil erosion weighted × 1.5; irrigation erosion × 1.5; runoff loss × 0.5; soil P test × 1.0; P fertilizer application rate × 0.75; P fertilizer application method × 0.5; organic P source application rate × 1.0; and organic P source application method × 1.0. Rating values for each level of these site characteristics were assigned (low = 1, medium = 2, high = 4, very high = 8), multiplied times their respective weighting values, and summed over the eight items. The resulting value provides the relative vulnerability of a site for P loss. This index has been applied in evaluating watersheds and although it may need refinement, it has been satisfactory in identifying P sources within a watershed that will require more management to minimize P loss in runoff and maintain crop productivity.

A more recent approach is simulation modeling through computer programs. This permits evaluation on a watershed basis and predicts the effect of various P management and cultural practices on potential P losses. This approach will probably require more input than the Phosphorus Index, which can be assessed with locally available information.

Management Practices Affecting Phosphorus Loss

Several management practices can affect P loss from agricultural fields. These include: soil test P level maintained; time, rate and method of P application; tillage that affects erosion and amount of crop residue on the soil surface; amendments to manure and soil to reduce P availability; and vegetative filter strips adjacent to surface water. Feed and feed additives can reduce the amount of P in animal manure.

Applying manure or fertilizer P to frozen or snow covered ground results in more P loss in runoff than when nutrients are applied to bare unfrozen ground. The P concentrations in runoff from the first rain after a surface manure application is greater than that in runoff from subsequent rains. As time between manure application and rain increases, P concentrations in runoff decrease. Timing of manure and fertilizer applications are important if these are surface applied. Injecting manure and banding fertilizer P into the soil eliminates most of the potential for runoff P.

Because of the relationship between surface soil test P values and loss of P in runoff and erosion, building and maintaining very high soil test P values becomes an environmental concern. Data from Iowa, obtained from a corn-soybean sequence grown on a soil with a very low subsoil level of P, show it may take a decade or more to reduce a very high soil test P to a responsive range (Figure 4). Also, economic returns are negative for maintaining very high soil test values, as shown in Figure 5 (Webb et al., 1992).

Tillage on soils where runoff and erosion will occur will increase total P loss with variable BAP concentrations and amounts as previously cited. No-tillage or very reduced tillage that leaves crop residue on the surface of similar soils will reduce total P and BAP loss, but may increase DP in runoff water. Periodic inversion of P-stratified surface soils may be advantageous to reduce concentrations of P at the soil surface and potential for P loss.

Amendments such as aluminum sulfate, ferrous sulfate or coal combustion products can be added to manure or soil to reduce soluble P. These amendments can affect other soil properties and should be investigated before applications of such amendments are recommended practice. An organic compound, polyacrylamide, has been used on western irrigated fields and has been shown to reduce loss of P and sediment from these fields.

Much of the P in corn grain is in the form of phytic acid, which is unavailable to monogastric animals (e.g., swine and chickens). Most grain P is excreted in manure. Phytase enzymes, added to feed rations, increase the availability of P in corn grain and reduce the amount of P excreted. Corn genetic material with a low phytic acid P content has been identified. Feeding trials using this corn grain has shown increased P availability to animals and reduced P content in manure (Ertl et al., 1998). Reduction of P concentrations in manure could reduce P loadings of fields where manure application is based on the nitrogen requirement of the crop to be grown.

Vegetative filter strips between agricultural lands and surface waters can be effective in reducing the amount of sediment and PP entering surface waters, but may increase the amount of DP in runoff waters.

Crop and Soil Management Options

Crop and soil management options exist to minimize potential P losses into surface waters.

1 Identify fields that have the greatest potential for P loss.
2. Apply fertilizer P or manure P according to soil test values for the crop to be grown.
3. Do not build and maintain excessively high soil test P levels.
4. Minimize soil erosion with appropriate cultural practices.
5. Where possible, incorporate or knife in fertilizer or manure without destroying crop residue required for soil conservation purposes.
6. Establish and maintain vegetative filter strips where runoff leaves a field and along streams and drainage ditches where agricultural runoff water enters these surface waters.
7. Grow high-P-removing crops that provide an economic return to the producer.
8. Periodically invert P-stratified surface soils by primary tillage.

Literature Cited

Baker, J. L., K. L. Campbell, H. P. Johnson, and J. J. Hanway. 1975. Nitrate, phosphorus, and sulfate in subsurface drainage water. Journal of Environmental Quality 4:406-412.

Bundy, L. G. 1998. A phosphorus budget for Wisconsin cropland. Report to The Wisconsin Department of Natural Resources and The Wisconsin Department of Agricultural Trade and Consumer Protection. Department of Soil Science, University of Wisconsin.

Daniel, T. C., A. N. Sharpley, and J. L. Lemunyon. 1998. Agricultural phosphorus and eutrophication: A symposium overview. Journal of Environmental Quality 27:251-257.

Duxbury, J. M. and J. H. Peverly. 1978. Nitrogen and phosphorus losses from organic soils. Journal of Environmental Quality 7:566-570.

Ertl, D. S., K. A. Young, and V. Raboy. 1998. Plant genetic approaches to phosphorus management in agricultural production. Journal of Environmental Quality 27:299-304.

Hergert, G. W., S. D. Klausner, D. R. Bouldin, and P. J. Zwerman. 1981. Effects of dairy manure on phosphorus concentrations and losses in tile effluent. Journal of Environmental Quality 10:345-349.

Lander, C. H., D. Moffitt, and K. Alt. 1998. Nutrients available from livestock manure relative to crop growth requirements. USDA-NRCS Resource Assessment and Strategic Planning Working Paper 98-1, Washington, D.C.

Lemunyon, J. L. and R. G. Gilbert. 1993. The concept and need for a phosphorus assessment tool. Journal of Production Agriculture 6:483-486.

National Research Council. 1993. Soil and water quality: An agenda for agriculture. National Academy Press, Washington, D.C.

Oloya, T. O. and T. J. Logan. 1980. Phosphate desorption from soils and sediments with varying levels of extractable phosphate. Journal of Environmental Quality 9:526-531.

Parry, R. 1998. Agricultural phosphorus and water quality: A U. S. Environmental Protection Agency perspective. Journal of Environmental Quality 27:258-261.

PPI (Potash and Phosphate Institute). 1994. Soil test summaries: Phosphorus, potassium, pH. Better Crops with Plant Food 78:14-17.

PPI/PPIC/FAR. 1998. Soil test levels in North America: A summary. Technical Bulletin 1998-3, Potash and Phosphate Institute, Norcross, GA.

Pote, D. H., T. C. Daniel, A. N. Sharpley, P. A. Moore, Jr., D. R. Edwards, and D. J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Science Society of America Journal 60:855-859.

Robbins, S. G. and R. D. Voss. 1991. Phosphorus and potassium stratification in conservation tillage systems. Journal of Soil and Water Conservation 46:298-300.

Romkens, M. J., D. W. Nelson, and J. V. Mannering. 1973. Nitrogen and phosphorus composition of surface runoff as affected by tillage method. Journal of Environmental Quality 2:292-295.

Schuman, G. E., R. G. Spomer, and R. F. Piest. 1973. Phosphorus losses from four agricultural watersheds on Missouri Valley loess. Soil Science Society of America Proceedings 37:424-427.

Sharpley, A. N. 1995. Dependence of runoff phosphorus on extractable soil phosphorus. Journal of Environmental Quality 24:920-926.

Sharpley, A. N. 1993a. An innovative approach to estimate bioavailable phosphorus in agricultural runoff using iron oxide-impregnated paper. Journal of Environmental Quality 22:597-601.

Sharpley, A. N. 1993b. Assessing phosphorus bioavailability in agricultural soils and runoff. Fertilizer Research 36:259-272.

Sharpley, A. N., T. C. Daniel, J. T. Sims, and D. H. Pote. 1996. Determining environmentally sound soil phosphorus levels. Journal of Soil and Water Conservation 51:160-166.

Sharpley, A. N. and S. J. Smith. 1991. Prediction of bioavailable phosphorus loss in agricultural runoff. Journal of Environmental Quality 21:32-37.

Sharpley, A. N. and S. J. Smith. 1989. Prediction of soluble phosphorus transport in agricultural runoff. Journal of Environmental Quality 18:313-316.

Sonzogni, W. C., S. C. Chapra, D. E. Armstrong, and T. J. Logan. 1982. Bioavailability of phosphorus inputs to lakes. Journal of Environmental Quality 11:555-563.

Triplett, G. B., Jr. and D. M. Van Doren, Jr. 1969. Nitrogen, phosphorus and potassium fertilization of non-tilled maize. Agronomy Journal 61:637-639.

Truman, C. C., G. J. Gascho, J. G. Davis, and R. D. Wauchope. 1993. Seasonal phosphorus losses in runoff from a coastal plain soil. Journal of Production Agriculture 6:507-513.

U. S. Environmental Protection Agency. 1986. Quality criteria for water. USEPA Rep. 440/5-86-001. USEPA, Office of Water Regulations and Standards. U. S. Gov. Print. Office (PB87-226759), Washington, D. C.

Van der Molen, D. T., A. Breeuwsma, and P. C. M. Boers. 1998. Agricultural nutrient losses to surface water in the Netherlands: Impact, strategies and perspective. Journal of Environmental Quality 27:4-11.

Webb, J. R., A. P. Mallarino, and A. M. Blackmer. 1992. Effects of residual and annually applied phosphorus on soil test values and yields of corn and soybean. Journal of Production Agriculture 5:148-152.

Wendt, R. C. and R. B. Corey. 1980. Phosphorus variations in surface runoff from agricultural lands as a function of land use. Journal of Environmental Quality 9:130-136.

Wolf, A. M., D. E. Baker, H. B. Pionke, and H. M. Kunishi. 1985. Soil tests for estimating labile, soluble, and algae-available phosphorus in soils. Journal of Environmental Quality 14:341-348.

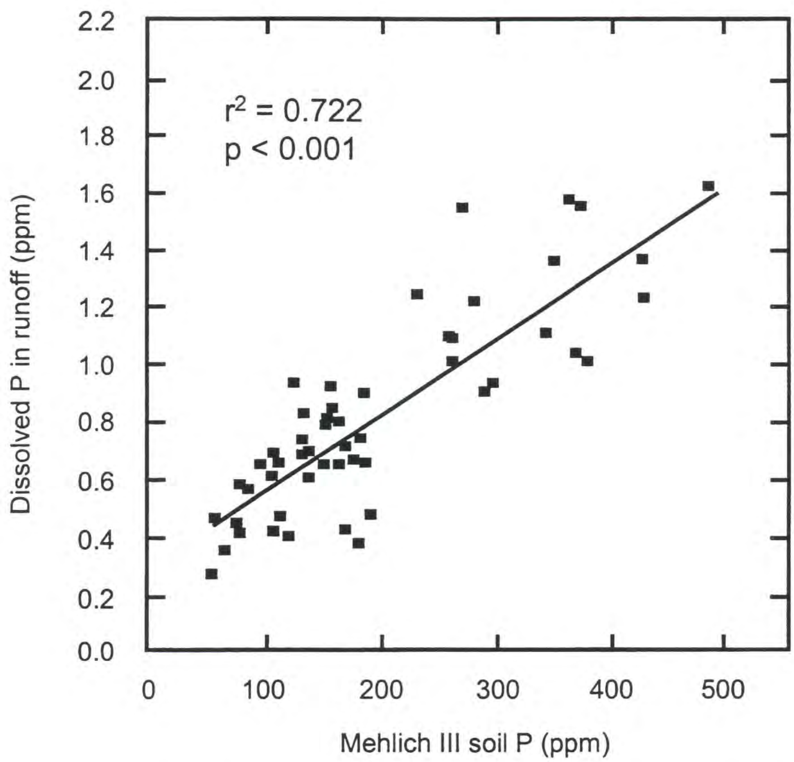

Fig. 1. Relationship between Mehlich III extractable P in Captina surface soil and dissolved P in runoff (adapted from Pote et al., 1996).

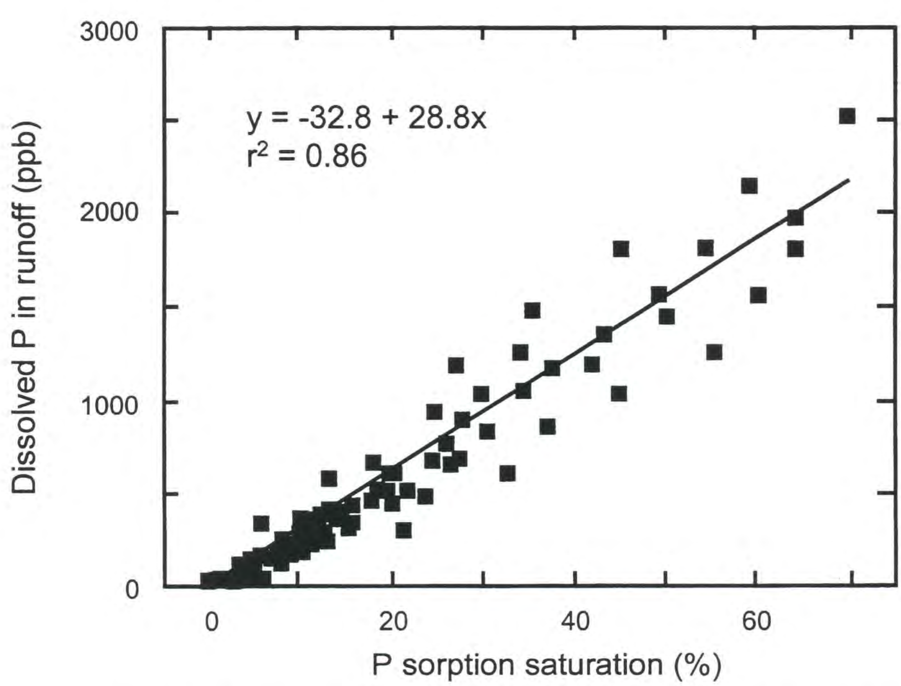

Fig. 2. Relationship between the dissolved P concentration of runoff and soil P sorption saturation of surface soil (0-0.4 inches), 7 d after poultry litter application. (Adapted from Sharpley, 1995.)

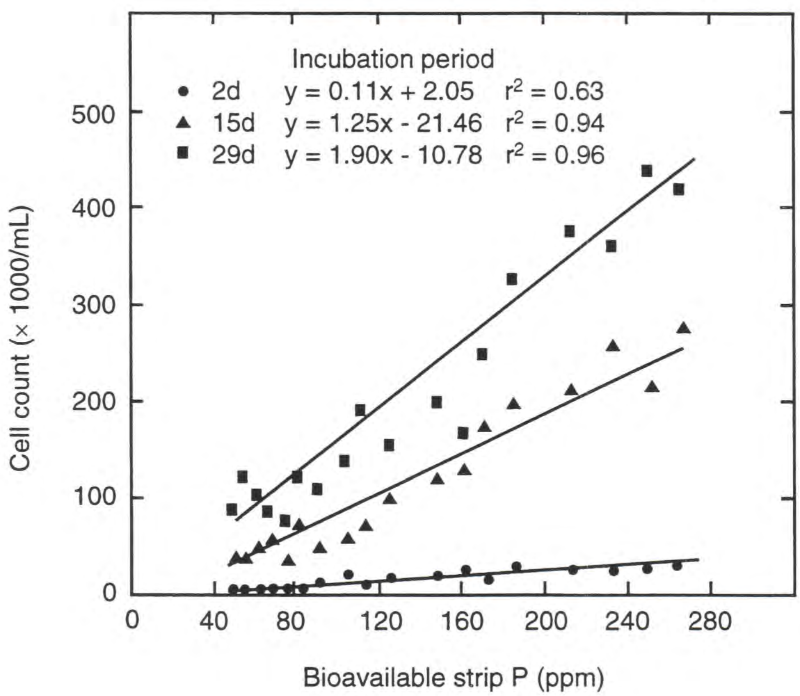

Fig. 3. Relationship between the bioavailable strip P content of runoff sediment and P-starved *S. capricornutum* (algae) growth during 2-, 15-, and 29-d incubations. (Adapted from Sharpley, 1993.)

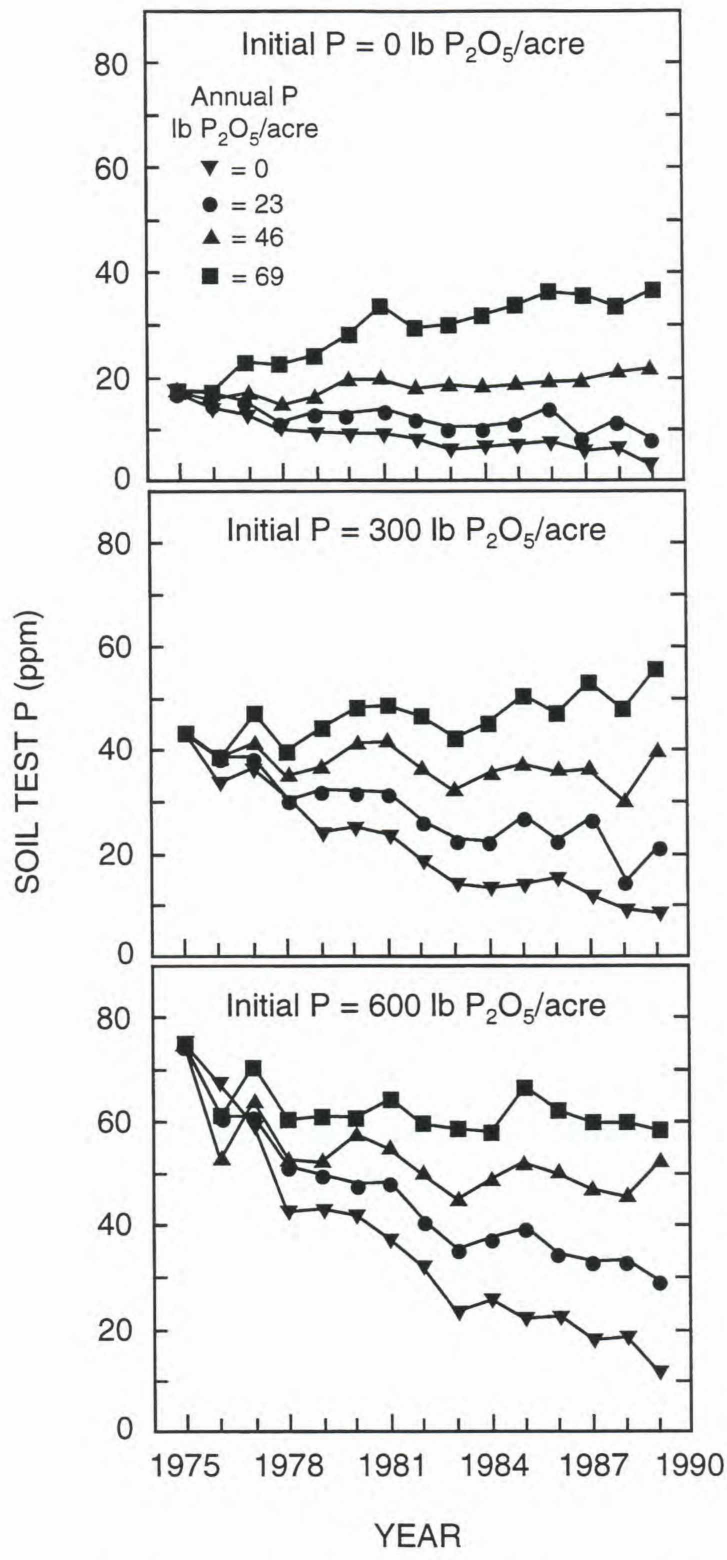

Fig. 4. Soil test P values (Bray-P_1) as affected by initial and annual applications of P fertilizer. (Adapted from Webb et al., 1992.)

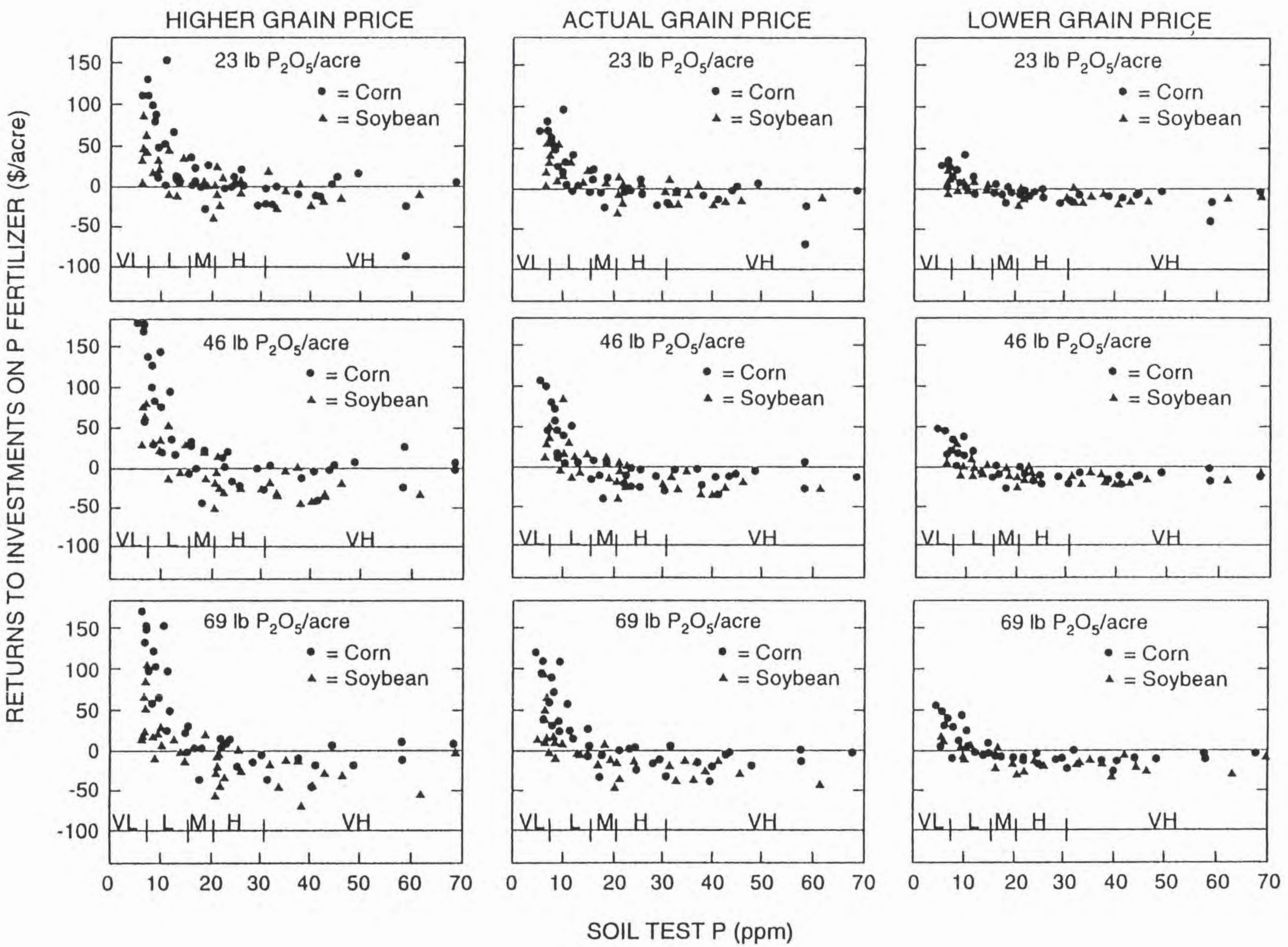

Fig. 5. Relationships between soil-test P values (Bray-P_1) and annual net returns to investments on three annual P rates at various grain prices. The actual prices were annual averages for the USA from 1976 to 1989. Higher prices were the prices for each year increased by 50%, and lower prices were the prices for each year reduced by 50%. (Adapted from Webb et al., 1992.)